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Procedia Environmental Sciences 16 (2012) 51 – 58
Procedia Environmental Sciences

The 7th International Conference on Waste Management and Technology

Distribution of heavy metals in core sediments from Baihua Lake

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Abstract

In the present research, five core sediments from Baihua Lake, a man-made reservoir located in the karst area on the Yunnan-Guizhou Plateau in China, were analyzed to study the distribution, origin and contamination of three selected heavy metals (Cu, Zn and Mn). The results showed that the concentrations of these heavy metals in sediments varied from different sampling locations and layers. The average concentrations of these heavy metals at the same sampling location followed the order of Mn > Zn > Cu. The mean concentrations of Zn and Mn in the samples at the depth of 0-5 cm and the depth of 5-10 cm of the core sediments were higher than those in the other layers. All of Cu, Zn and Mn presented similar distribution characteristics at sampling site CFZ, and different distribution characteristics from the other four sampling locations. A statistical analysis indicated that there were some correlations between the concentrations of these three heavy metals and other studied six elements occurring in the core sediment samples. Three components were obtained with principal component analysis (PCA) analysis of heavy metals concentrations in core sediment samples.

Keywords: Baihua Lake; heavy metals; distribution; core sediments.

1. Introduction

Bottom sediments, as one of basic components of a water body, provide foodstuffs for benthic living organisms [1]. They have always been considered as a reservoir for a wide variety of environmental contaminants, and usually also provide a record of catchment inputs into aquatic ecosystems [2-4]. It has been well recognized that aquatic sediments absorb harmful chemicals to levels significantly higher than

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doi:10.1016/j.proenv.2012.10.008

the water column concentrations. Surface sediment accumulates contaminants and may act long-term storage for heavy metals in a water body. These contaminants would be released into water column as an endogenic source of contamination due to alteration of sediments oxidation-reduction status consequently causing pressure on the aquatic food chain. Therefore, the pollution of heavy metals in the sediments has become one of important environmental issues [5-8]. Generally, sediments are always selected to serve as an indicator for aquatic ecosystems pollution. The distribution characteristics of contaminants in sediments could provide some useful information of contaminants including transformation and migration. In combination with some details of the sediment circumstances and statistical analysis, more in-depth information concerning contaminants' origin could be obtained.

Baihua Lake (E 106o 27' -106o 34'，N26o 35' -26o 42'), located on the Yunnan-Guizhou Plateau in southwest China, is one of the five drinking-water sources for approximately three million population of Guiyang City, the capital of Guizhou Province [9]. It is a multifunctional water system not only for drinking water provision, but also for flood control, shipping, and fishery. Since the lake is situated in Qingzhen County, only 16 km northwest of Guiyang City, it is susceptible to accumulation of various pollutants in sediment. Although some studies concerning heavy metals pollution in grab-bucket sampling in Baihua Lake had been conducted, few of them have addressed on the distribution characteristics of heavy metals in core sediment samples [1, 9]. The main objectives of this research were to study distribution characteristics of Cu, Zn and Mn in core sediment samples from Baihua Lake, and to employ some statistical methods to explore useful information regarding origin and migration of the three heavy metals.

2. Materials and methods

2.1. Sample collection and preparation

Five core sediment samples were taken with a core sediment-sampler in June 2011 from five locations in Baihua Lake, which were selected based on the size, shape, and water-flowing direction of the water body. The sampling locations are as follows: Guanyinshanzhuang (GYSZ), Jinyinshan (JYS), Dahewan (DHW), Yapengzhai (YPZ), and Chafanzhai (CFZ) (Fig. 1). Each core sediment sample was cut into four parts (0-5, 5-10, 10-15 and 15-20 cm) and sealed in polyethylene bag on the spot, and taken to our laboratory immediately [10].

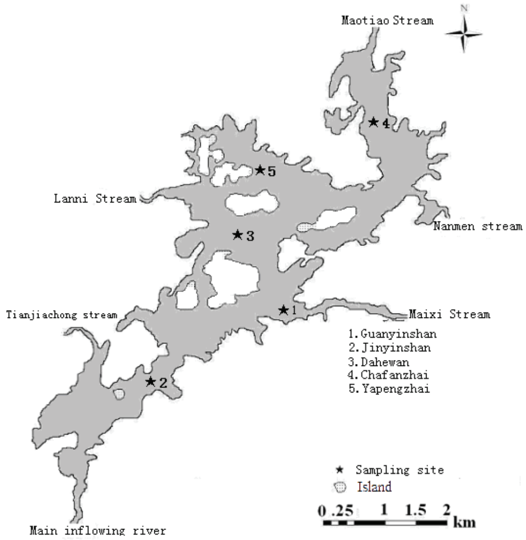


Fig.1. Distribution of sampling sites in Baihua Lake

In the laboratory, the sediments were centrifuged and the supernatants were discarded. The resulting sediment materials were dried at room temperature and then ground into powder for analysis. The leftover was kept for backup.

2.2. Instruments and reagents

The following instruments were used in this research：Inductively coupled plasma atomic emission spectrometry (ICP-AES, Optima 5300V) was from Perkin Elemer Corporation, USA; water purification system (Nex Power 2000) from Human Corporation, Korea. In this study all reagents used were made in China. The hydrochloric acid (HCl), nitric acid (HNO_3), and perchloric acid ($HClO_4$) were guaranteed reagents, and the other reagents were with analytic grade.

2.3. Sample analysis

To analyze the total concentration of the heavy metals in core sediments from Baihua Lake, 0.5000 g of each sample was weighed accurately in a 250-ml beaker and 20 ml of digesting mixture made up of concentrated nitric acid and concentrated perchloric acid (nitric acid: perchloric acid = 4:1 (V/V)) was added. The beakers were placed on an adjustable electric heating-plate, and heated with low temperature for 60 min; then the electric heating plate was adjusted to the highest temperature and the heating was continued until a small amount of solution was left and the color of digestion solution was changed to the white. The remaining solution and sediment was transferred into a 50-ml volumetric flask and diluted to the full volume with 0.5% (V/V) nitric acid solution. The solutions prepared above were used to determine with ICP-AES the total amount of Mn, Cu, Zn, K, Na, Ca, Mg, Fe and Al.

3. Results and discussion

3.1. Distribution of Cu, Zn and Mn and the other six elements in the core sediments

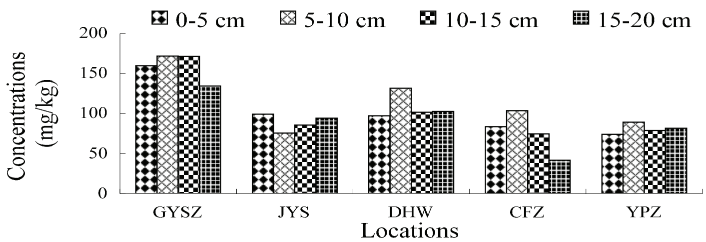
Levels of Cu, Zn, Mn, Na, K, Mg, Ca, Fe and Al at different depths of core sediments from Baihua Lake are listed in Table 1. It is clear that the concentration ranges of concerned heavy metals vary significantly from each other. The concentrations of Cu, Zn, Mn ranged from 41.83 to 171.9 mg/kg (dry weight，DW), 67.52 to 325.1 mg/kg, and 406.3 to 3340 mg/kg , with the mean values of 102.71, 184.33, and 1780 mg/kg, respectively. The mean concentrations of these three heavy metals decreased in the order of Mn > Zn> Cu, and the mean concentrations for the other six elements in the order of Fe (5.39%) > Al (3.08%) > Ca (2.49%) > Mg (1.04%) > K (0.67%) > Na (118.31 mg/kg). It was evident that each heavy metal in the core sediments showed its own distributing characteristics.

Fig. 2(a) shows the distribution characteristics of Cu. Clearly, Cu concentration in the top five centimeters of core sediment samples were much higher than those in the deeper core sediment samples with the exception of the core sediment sample from sampling location YPZ. As shown in Fig. 1, sampling location YPZ is not located in the water flowing direction like the other sampling locations. This was probably the main reason why Cu concentrations in the top five centimeter sediments were lower than those in sediments at the depth of 5-10 cm. In addition, Cu concentrations in all core sediment samples show the following tendency along the depth: 5-10 cm >0-5 cm > 10-15 cm > 15-20 cm with the exception of sampling site JYS. This might be associated with organic compounds, sulfides, Fe/Mn oxides/hydroxides, and microbial activities. In previous studies, the authors found that the distribution characteristics and speciation of Cu in the surface sediment sample in this lake was associated with organic matter and sulfides [9, 10]. Distribution characteristics of Zn are shown in Fig. 2(b). Obviously, concentration of Zn in the top five centimeters of sediment fluctuated significantly from different sampling locations, and its highest and lowest value occurred at sampling locations YPZ and CFZ, respectively. Just like Cu, at sampling location CFZ, its concentrations in different layers were close. The concentrations of Zn occurring in sediment samples at the depth from 5-10 cm and from 10-15 cm decreased along the water flowing direction. This phenomenon probably implies that the final sinking part of Zn in this water body was associated with some factors affected by water flow, such as temperature, organic matter, concentrations of nutrient elements. Fig. 2(c) shows the distribution characteristics of manganese. Similarly to Zn, concentration of Mn in top five centimeters of sediment fluctuated significantly from different sampling locations, and its highest and lowest value occurred at sampling locations YPZ and CFZ, respectively. In contrast to Cu and Zn, Mn has close values of concentrations for different layers at sampling site CFZ.

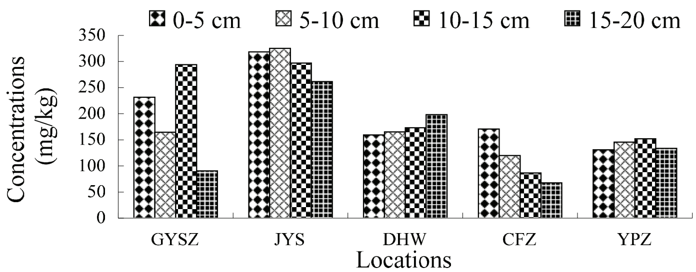
Table 1. Concentrations of Cu, Zn, Mn and the six other elements in sediment (dry weight, DW).

Sampling sites	Layers (cm)	Na (mg/kg)	K	Mg	Ca	Fe	Al	Cu	Zn	Mn
			(%)					mg/Kg		
GYSZ	0-5	173.6	0.63	1.45	6.96	6.38	3.68	159.9	231.5	1931
	5-10	178.0	0.85	1.40	1.02	6.52	4.73	171.9	164.8	1693
	10-15	142.3	0.68	1.18	2.09	7.56	3.81	171.4	294.1	2293
	15-20	53.87	0.61	0.91	0.36	6.44	3.82	134.4	90.71	406.3
JYS	0-5	207.3	0.79	1.78	7.00	4.12	3.35	99.22	318.4	2941
	5-10	125.5	0.68	1.47	4.74	3.96	3.08	75.63	325.1	2853
	10-15	171.0	0.80	1.43	4.38	4.01	3.23	85.78	297.2	2894

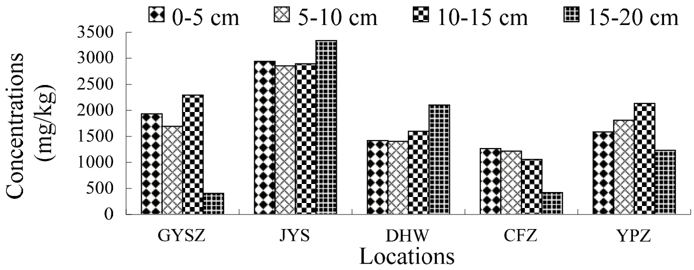
	15-20	157.5	0.87	1.55	2.10	4.13	3.49	94.40	261.4	3340
DHW	0-5	123.4	0.62	0.85	3.60	4.29	2.19	97.37	159.4	1418
	5-10	127.1	0.71	0.82	0.73	7.23	3.18	131.7	165.3	1406
	10-15	117.1	0.73	1.00	1.34	5.35	3.08	101.7	173.2	1597
	15-20	86.19	0.61	0.65	0.82	5.76	2.58	102.6	198.1	2103
CFZ	0-5	137.1	0.59	0.92	3.50	3.82	2.82	83.66	170.8	1266
	5-10	148.0	0.82	1.13	1.93	4.15	3.61	103.7	119.9	1216
	10-15	118.1	0.76	1.03	1.67	3.51	3.12	74.78	86.63	1056
	15-20	40.58	0.50	0.66	0.32	2.40	2.76	41.83	67.52	420.8
YPZ	0-5	66.37	0.50	0.83	3.96	4.35	1.70	74.12	131.1	1585
	5-10	75.68	0.52	0.72	1.49	7.96	2.45	89.30	145.7	1810
	10-15	50.38	0.50	0.54	1.22	9.11	2.46	78.94	152.0	2132
	15-20	67.13	0.61	0.49	0.58	6.84	2.45	81.80	133.7	1232
Mean		118.31	0.67	1.04	2.49	5.39	3.08	102.71	184.3	1780



(a) Distribution of Cu in core sediments from Baihua Lake



(b) Distribution of Zn in core sediments from Baihua Lake



(c) Distribution of Mn in core sediments from Baihua Lake

Fig. 2. Distribution of Cu (a), Zn (b) and Mn (c) in core sediments from Baihua Lake.

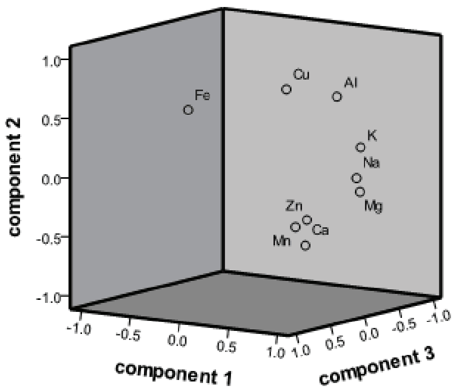
3.2. Statistical analysis of concerned heavy metals and the other six elements

To explore the correlations between the concerned heavy metals and the other six elements, the Pearson correlation analysis was employed, and the results are shown in Table 2. Correlations between heavy metals may reflect some information of origin and migration about these elements. For example, high correlations between two heavy metals probably mean these two elements share similar pollution sources or they share analogous transformation and migration processes in the certain circumstances. Obviously, Na showed positive correlations ($p < 0.05$) with all studied elements with the exception of Fe. The correlation coefficient between Na and Cu was 0.463, between Na and Zn was 0.664 ($p < 0.01$), and between Na and Mn was 0.589 ($p < 0.01$). As presented in Table 2, as a major element, the Na concentrations in the core sediment samples from Baihua Lake were low. This might be mainly associated with the fact that Na was working as a limited factor which refrain the microbial activities in sediment from this water body, and that Na was affecting the distribution characteristics of other elements through an indirect way. Potassium poses no significance correlations to Cu, Zn and Mn. Mn showed significant correlations to Zn ($r = 0.719$, $p < 0.01$) and Mg ($r = 0.632$, $p < 0.01$). Ca also showed significant correlations to Zn ($r = 0.640$, $p < 0.01$) and Mn ($r = 0.521$, $p < 0.05$). Fe and Al showed significant correlations to Cu with the correlation coefficients of 0.509 ($p < 0.05$) and 0.714 ($p < 0.01$), respectively. In addition, there was also a significant correlation between Zn and Mn, its correlation coefficient was up to 0.896 ($p < 0.01$). It is well known that Mn is an oxidized and reduced condition sensitive element. Therefore, oxidized and reduced condition may be a main potential factor affecting distribution characteristic of Zn in this water body.

Table 2 Pearson correlation coefficients between heavy metals

	Na	K	Mg	Ca	Fe	Mn	Cu	Zn	Al
Na	1								
K	0.791**	1							
Mg	0.867**	0.736**	1						
Ca	0.618**	0.142	0.670**	1					
Fe	-0.220	-0.251	-0.335	-0.303	1				
Mn	0.564**	0.423	0.632**	0.521*	0.028	1			
Cu	0.463*	0.357	0.342	0.055	0.509*	0.078	1		
Zn	0.664**	0.416	0.719**	0.640**	-0.025	0.896**	0.245	1	
Al	0.589**	0.699**	0.622**	0.002	0.084	0.112	0.714**	0.252	1

*Significant at 0.05 level (two-tailed), ** Significant at 0.01 level (two-tailed).



	Components		
	1	2	3
Na	0.938	——	——
K	0.779	——	——
Mg	0.954	——	——
Ca	0.635	-0.529	——
Fe	——	0.615	0.737
Mn	0.723	——	——
Cu	0.466	0.777	——
Zn	0.816	——	——
Al	0.632	0.661	——

Fig. 3. PCA analysis of heavy metals and some other elements in sediment samples.

As shown in Fig. 3, three principal components were obtained through principal component analysis (PCA) of the concentrations of the heavy metals in core sediment samples. In this study, the correlation was considered as loading score larger than 0.500. It is worth noting that all studied elements have high positive loading scores to component 1 except Fe and Cu. Calcium poses a negative loading score to component 2, while Fe, Cu and Al pose positive loading scores to this component. Iron only shows a loading score to component 3.

4. Conclusions

The concentrations of Mn, Zn and Cu at the same sampling sites followed the order of Mn > Zn > Cu. Mn was the major polluting heavy metals since its average concentration was much higher than those for the other two heavy metals. Pollution of Zn and Mn at sampling site JYS was more serious than that at the other sites. Although these results are only an approximate assessment since mobility, bioavailability and toxicity of heavy metals are closely associated with their chemical speciation, the present study can present overall pollution status of theses heavy metals pollution in the core sediments, and can thus provide the government and researchers working on management and restoration of Baihua Lake with some useful information for drafting remediation measures, e.g. environmental dredging of the sediment.

Acknowledgment

This work was financially supported by the National Natural Science Foundation of China (Project No. 20967003).

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